# Science, Government, and Industry

SIR EDWARD V. APPLETON, K.C.B., F.R.S.

Secretary to the Department of Scientific and Industrial Research, an Agency of His Majesty's Government

**Today science is too serious a matter to be left to the scientist . . . The consequences of his work must be interpreted to his fellow men, and decisions on its use be made by the communit·**

I HAVE chosen as the subject of my lecture "Science, Government, and Industry" because I believe that the proper direction of scientific effort and the proper application of the results of such effort is one of the most important challenges of our time. It seems to be typical of any postwar period that fundamental matters come under fresh scrutiny and fearless examination, and it is surely a good thing that this should be so. Stimulated by the realization of the magnificent services rendered by scientists in support of the allied forces during the war, science and its consequences have become a matter of interest to the ordinary citizen. It is no new thing to the thoughtful mind that science has practical and social consequences. What is new is that the general public is now sharply aware of them. As a prominent newspaper man recently expressed it to me, "Science is news, as never before."

Now I think it can be said that this awakening to the importance of scientific work on the part of the public has been due in large measure to the fact that, during war, events move fast, and the four stages of research, development, production, and use follow so rapidly on the heels of one another that the practical consequence of scientific effort is clear for all to see. The public has naturally concluded that if science can solve so many of the problems of wartime, it should play a similar role in solving the problems of peace. The problems that confront us now are, in an ultimate analysis, the provision of work, homes, food, health, and safety—safety from aggression—for all; and these problems depend for their solution on the maintenance, in some degree, of the same kind of partnership between government, science, and industry which grew up during the war. It is to some aspects of this partnership that I want to invite your attention.

But I feel I ought, at the outset, to say that any conclusions I may put before you are necessarily drawn from my experience in Britain. It would be improper, even if I were well informed on the subject, and that is certainly not the case, for me to comment on the American scene. Nevertheless, I feel that much that I have to say, particularly concerning the scientist himself as distinct from the organization of which he is part, may well be applicable in both your country and mine.

Now I think it is helpful in approaching the problem of the future to cast a brief glance at the war years which have just passed, for I feel that we can draw certain lessons from that experience. In Britain the whole of our scientific manpower was registered and debarred from entering the armed forces without special permission, in 1939. There was thus a reservoir of trained people for recruitment to the research establishments serving the Navy, Army, Air Force, and Civil Defense organizations. But even then the recruitment did not take place indiscriminately. The general policy adopted was not to recruit men from industrial research teams. These teams were left practically intact. But in the case of university workers, who are generally more accustomed to work singly or in small groups, an opposite policy was adopted. The result was that the research establishments of the services were strengthened by the addition of many brilliant minds from the universities while the research teams in industry were ready to attack, as composite units, the problems allotted to them.

Now one of the most striking results of our wartime experience has been the brilliant success of our university research

workers in solving war problems entirely remote from their peacetime interests. Various reasons have been advanced for their success. It has been pointed out that they had fresh minds. It has also been stated that in approaching a difficult task "they didn't know it couldn't be done." It has further been claimed that they had a better background of fundamental principles than the majority of those with whom they worked. I do not profess to be able to assign the result to any one of these causes. But what cannot be doubted is that university conditions certainly do, somehow, generally ensure the maintenance of mental adventurousness and lively imagination so necessary for scientific progress.

Another deduction I make from our wartime experience is that the most successful applications of science have resulted from the closest possible collaboration between the scientist and the military staff—that is to say, between the "provider" and the "user." Your great naval writer Rear Admiral A. T. Mahan, once drew attention to the long period which used to elapse between changes of weapons and the consequent changes of tactics. He attributed this lag to "the inertia of a conservative class." Fortunately we can be satisfied that in the war that has just ended such gaps have not been unduly long. This has been due not only to the close collaboration between scientist and serviceman but also to the fact that in many cases scientists have assisted their service colleagues in working out plans for the use of new weapons and have been able to make post-mortem analysis of operational results whereby to check these plans. Indeed it has been realized that the field in which the scientist can usefully operate extends far beyond that of the laboratory.

### *Many Avenues Sidestepped*

My third comment on our wartime experience relates to subject matter. We have seen a mighty effort resulting in outstanding developments in weapons and instruments, culminating in the atomic bomb. By no means all this effort has been wasted, even if judged solely by its peacetime scientific interest and importance. But in this intensive drive many inviting scientific avenues have had to be just noticed and passed by. When fundamental work has had to be done, as in the case of nuclear physics or in radio wave propagation, it has necessarily had to be

objective in character and relevant to the major target. What I may call free fundamental work—free in the sense that its selection is dictated solely by man's curiosity—has been almost wholly in abeyance. We cannot recognize the return of peace in any better way than by changing all that. We have in many fields been living on our scientific capital which now stands urgently in need of replenishment. For this purpose the British Government has set its own priorities, for the time being, as regards the release of scientific staff from Government service in the following order:

1. Universities and fundamental research.
2. Civil science, government and industrial.
3. Defense science.

You will see in this a complete reversal of the priorities which obtained in wartime.

### *Civil Science*

In turning now to the future we note that, as in most countries, scientific research in Britain is in the main carried out by three types of organizations which differ somewhat in motives and objectives. These three organizations are:

a. **Universities** and like institutions carrying out what I shall call free fundamental research, for the purpose of extending the endless frontiers of knowledge, if I may use the graphic expression of Vannevar Bush. This type of research, the result of intellectual curiosity and the love of truth for its own sake, is carried out without regard to any immediate or future useful application.

b. **Government establishments** carrying out what I may call objective fundamental research and also applied research. By objective fundamental research I mean research designed to give insight and understanding rather than any special immediate practical result. It is called objective because it is relevant to some field of practical importance.

c. **Industrial research laboratories** carrying out mainly applied research but also, in enlightened firms, a certain amount of objective fundamental research.

But I do want to emphasize here that there is no sharp differentiation between my divisions into (a) free fundamental, (b) objective fundamental, and (c) applied, research. However, I do find them a more convenient classification than the older division into "pure" and "applied" research which always had, to my mind, the suggestion of snobbishness about it. A certain mathematician once stated that "Bessel functions are beautiful functions in spite of their many applications," and I well remember hearing a British scientist boast that he could claim that what he had done could never be the slightest use to anybody. It turned out to be an idle boast, as we might have expected. His work has become of great practical importance.

### *University Science*

It is a remarkable fact that university scientific research is of relatively modern growth. Scientific research, as we know it today, began in the seventeenth century when the experimental method replaced the method of *ex-cathedra* statement or argument by which, since the Middle Ages, man had endeavored to find truth. The scientific method of inquiring by observation, theory, and experiment has often been attributed to Francis Bacon, though my own view is that William Gilbert, the physician of Queen Elizabeth and fellow of my own college, St. John's at Cambridge, has a stronger claim to be counted its author. But the teaching of the experimental method did not form part of the university curriculum in the seventeenth and eighteenth centuries, and laboratories did not form part of university equipment. Early in the nineteenth century, however, teaching laboratories for science were instituted and research became a spare-time activity of professors and lecturers. From small beginnings this has developed till it is now an accepted part of university tradition that teachers of scientific knowledge should also advance that knowledge. It is moreover important to note that, though carried out in a spirit of pure inquiry, this free fundamental research has shown a surprising capacity for being useful.

Then we also look to our universities not only to make science but to train makers of science. We look to them for the supply of trained scientific workers who will later occupy positions in university, government, and industrial laboratories. We find that this training in research is best accomplished by a senior research worker acting as supervisor to a group of research students which should not be large.

We must never forget the outstanding importance of the exceptional man in this respect. Most of the really great advances in science have been accomplished by small teams of workers of this kind led by a man with ideas. As one concerned, to some extent, with the organization and support of science in Britain, I believe that a vital task is to see that these leaders, these men with ideas and inspiration, lack neither disciples, assistants, nor equipment. When such needs have been satisfied they should be left alone.

### *Government Science*

I now turn to government research. Even apart from defense research, government in Great Britain conducts a great deal that perhaps you would regard as being primarily the responsibility of industry or other bodies. Here we definitely enter the utilitarian field.

Though their object was in the main the satisfaction of their disinterested intellectual curiosity, the natural philosophers of the seventeenth century easily recognized that the results of their experiments could lead to important applications. Not only did they appreciate the importance of what Bacon called *experimenta lucifera*—experiments of light, which illuminate our knowledge of the nature of things—but they also appreciated what he

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Arthur Dehon Little, 1863–1935, was most widely known as a pioneer in the application of science to industry.

He was a member of the class of 1885 at the Massachusetts Institute of Technology. Following a brief period in the paper industry, Dr. Little opened a commercial chemical laboratory in Boston. By 1917 this venture had become a model industrial research laboratory, the home of Arthur D. Little, Inc., "dedicated to industrial progress."

Dr. Little's interest in the education and training of young men in the advanced study of chemical technology led to the inauguration of the Research Laboratory of Applied Chemistry and the Chemical Engineering Practice School at MIT.

He was president of the American Chemical Society for two terms, 1912 and 1913; president of the American Institute of Chemical Engineers, 1919, and president of the British Society of Chemical Industry, 1928. In 1929 Dr. Little received the degree of doctor of science from the University of Manchester; in 1931 he was awarded the Perkin Medal.

The Arthur Dehon Little Memorial Lectureship was established at MIT in 1944, less than ten years after Dr. Little's death. However, because of wartime dislocations, the first lecture was delivered only last fall. In line with the purpose of the lectureship to promote interest in and stimulate discussion of the social implications inherent in the development of science, Sir Edward V. Appleton, K.C.B., F.R.S., secretary to Great Britain's Department of Scientific and Industrial Research, was invited to deliver the inaugural lecture.

Sir Edward has cited a tribute paid to Dr. Little that perhaps epitomizes his life: "A genuine leader in the preservation and advancement of that organized body of knowledge which we know as Science . . . one who pursued science with true dignity."

called *experimenta fructifera*, experiments of fruit, which yielded knowledge which could be applied, as Bacon pointed out, to extend the empire of man and to ameliorate the condition of man which he regarded as wretched. In his "New Atlantis" Bacon described what he calls Solomon's House, a kind of national research laboratory which had the object of arriving at "the knowledge of causes, the secret motions of things, and the enlarging of the bounds of human empire, to the effecting of all things possible." You will be interested to note that of the staff for this national laboratory he writes: "We have three that try new experiments such as themselves think good. These we call pioneers. We have three that bend themselves, looking into the experiments of their fellows and cast about how to draw out of them things of use and practice for man's life and knowledge. These we call benefactors. Lastly we have three that raise the former discoveries by experiments into greater observations, axioms, and aphorisms. These we call interpreters."

Somewhat later the scholarly Boyle, too, discoursed largely on the "usefulness of the experimental natural philosophy" pointing out the usefulness of mechanical disciplines to natural philosophy and how the goods of mankind may be increased by the naturalist's insight into trades, and of doing by physical knowledge what is wont to require manual skill.

The close of the eighteenth century brought from America to Great Britain and Europe that singularly gifted secretary, general, and statesman, Benjamin Thomson Count Rumford who, while making several purely scientific discoveries of the highest importance, found practically the whole of the inspiration of his scientific work in his desire to use science to improve the living conditions of the common people. He was, I think, the first, conscientiously and deliberately, to use science as a means of increasing health, happiness, and comfort of his fellow man.

### *Science Once Merely a "Curiosity"*

Very little was heard in the nineteenth century of the possibly useful applications of science, which was still studied in the main for its pure intellectual interest. I recently, however, came across a most interesting article written in the *Fortnightly Review* in 1873 in which the author, George Gore, F.R.S., points out that scientific research is the only source of the new knowledge which is indispensable to national progress. As he says, "Without new knowledge the thoughts of men run in circles and intellectual and material progress ceases."

After calling attention to what he calls the deplorable lack of support given to fundamental scientific research, he proposed that there should be formed state laboratories for original research. In the course of his article he quotes a number of examples of what we would now call gaps in our fundamental knowledge and also a number of scientific problems whose solution he claims would be of great value to industry.

Many of the problems he mentions have now been solved. In his suggestion for state laboratories he is somewhat troubled in his mind about the need to ensure that, with no set duties beyond instruction to carry out research, a man would not become idle. His ideas would raise a smile in these days for he writes: "Men who had previously exercised the degree of self-sacrifice necessary to make a number of long and difficult experimental researches, with only very limited pecuniary means, must necessarily be possessed of great enthusiasm in their calling, and would therefore be extremely unlikely persons to become idle by being supplied with a sufficiency only of means to carry on their labors. But in order to exclude with certainty those who might hereafter devote themselves to research solely or primarily for the purpose of obtaining a well-paid appointment, and to insure in all cases a reasonable continuance of industry, it would be necessary, that whilst the salaries paid should be sufficient to render the professors free from care, if expended with a reasonable degree of economy, they should not be so large as to conduce to idleness."

Very little notice seems to have been paid to these advocates of state assistance in the prosecution of research for the national benefit in Great Britain until, in 1900, the National Physical Laboratory was founded with government assistance.

### *Science in World War I*

It required the impact of the first World War, however, seriously to awaken the British Government to the necessity for state action in regard to scientific research and, as a result, in 1915 the Department of Scientific and Industrial Research was established as a separate Department of State, under the Lord President of the Council who is advised by an advisory council. The Department of Scientific and Industrial Research is not, of course, concerned with the whole field of science. Agricultural research and medical research are dealt with by sister organizations, also under the Lord President. There are naturally, scientific experts in the ministries responsible for defense, trade, food, health, fuel, transport, and so on, so that, very wisely I think, there has been no attempt to confine scientific knowledge to one ministry alone, since it has to be applied by many.

The major part of government civil research in the sphere of physical, chemical, and industrial interest is, however, centered in a group of ten research organizations under the Department of Scientific and Industrial Research (DSIR) through which we try to provide a central scientific service for the executive departments of government and also to carry out research on matters of common interest to industry and to the community as a whole. That is the first function of the department. Our second is the encouragement of research by industry itself, and more directly by fostering the formation of cooperative research associations, of which I shall have more to say later. Thirdly we assist, by means of grants, free fundamental research of timeliness and promise in universities in Great Britain, and we endeavor to provide an adequate supply of trained research workers by means of maintenance allowances.

### *British Research*

But before I mention further details of the department's activities I would like to draw your attention too to the special position allotted by our founders to the advisory council which advises the Lord President on all the department's research activities and expenditure. At present this expenditure is running at the rate of £3,000,000 per year. The advisory council is composed of men who have an expert knowledge of science or of industry and who serve in their purely personal capacity and not as representatives of any particular organizations to which they belong. It was, when first formed, one of the first bodies composed of men outside government to advise on policy for implementation inside government. Individual members of the advisory council retire after five years' service.

In addition to the advisory council we have a research board or committee to advise on the work on each of our research organizations. Each board or committee is, again, composed of independent members who are chosen by the Lord President for their special knowledge and experience. Thus, by way of our various advisory bodies, our university and industrial scientists and our industrial leaders exercise a direct influence on the activities of the department.

I now turn to say a word or two about our own ten research establishments. The full list of the department's stations is as follows: National Physical Laboratory, Building Research Station, Chemical Research Laboratory, Food Investigation Organization (dealing with the storage and preservation of food), Forest Products Research Laboratory, Fuel Research Station, Geological Survey, Pest Infestation of Stored Products, Road Research Laboratory, and Water Pollution Research Laboratory.

Now I think it is important to note that our research stations, which seek to advance knowledge of community interest, are differentiated according to objectives. The staff of each of the stations is constituted as a balanced team of physicists, chemists, engineers, architects, biologists,

and others according to the objective of the station. In addition, there are three stations organized subjectively, the National Physical Laboratory, by far the largest station of the department, the Geological Survey, and the Chemical Research Laboratory. In addition to work on their own extensive program, these organizations naturally give specialist services to all the other stations in their own subjects.

As I think I have made clear already, the Department of Scientific and Industrial Research is not an executive department of state. It provides a central scientific service for all possible government and industrial users of its knowledge and results.

### *Role of Government*

Now in considering the applications of science we must note the changing function of government. In Graham Wallas's famous phrase, it "has come to be engaged not merely in preventing wrong things from being done, but in bringing it about that the right things shall be done." In discharging this most positive function we find that, to an increasing extent, science is being used as part basis for the formulation of government policy. A very interesting problem of organization therefore arises. We desire scientific knowledge to permeate the executive departments. How far, then, can a central scientific department serve these executive departments, and in what way should its service be supplemented by scientific staff and scientific work within the executive departments themselves? I do not pretend to be able to give, in answer to these questions, a simple formula which would be applicable to all cases. But quite extreme views have been expressed in Britain on this subject. It has been argued by some that all science should be made in a central scientific department and none in the executive departments. It has been correspondingly argued by others that each executive department should have sufficient scientific staff to make all the science which it needs in the discharge of its own responsibilities. The latter answer seems to me to overlook the need for economy of scientific effort. Because the police need wireless, as do so many other civilian and military services, there seems no case for the home office to set up its own radio research unit if it can be equally well served by a central radio research organization. Correspondingly, there is no need for the Ministry of Health, which is responsible for our pure water supply, and the Ministry of Fuel and Power, which is responsible for our mining development, both having their own geological survey units. So I would argue that there are weighty economic reasons for the use of some, even if not all, common scientific services.

But, granted that there are some central scientific services, how can we ensure that their work can be effective in the executive departments? It seems to me entirely unfair to expect the normal administrative staff of such departments to play the full role of "user" in this connection.

One solution of this difficulty is the appointment of a scientific adviser in each executive department, who can (a) identify the problems within his department which are suitable for scientific treatment; (b) see that these problems are passed to the appropriate research bodies able to solve them; and (c) interpret the incoming scientific material for the special purpose of his department. But I should stress that for such a scientific adviser to be effective it is necessary that he should be sufficiently senior in the department hierarchy. His advice should be tendered to the highest level—the level at which policy is decided.

I have so far stressed the value of the work of DSIR to government and, through government, to the community. But there is also another link with the community, and that is through industry. In this connection the department serves industry chiefly by conducting research on generic fundamental problems on the basis of which industry itself can make applications. The greater part of this research is what I called objective fundamental research. In this case the main quest is understanding. Here the scientist seeks physical or chemical insight, and even atomic insight, into certain fields of practical importance. This may relate to the corrosion of metals, the oxidation of fats, the toughness of meat, the warping of wood, the electronic changes in the ionosphere, and so on. Armed with understanding, many practical problems are relatively easily solved. Very often a basic attack of this kind is the most fruitful and shortest route to the solution of a problem of practical importance. Also, very often quite unexpected and unsought applications are thrown up as by-products of such fundamental research.

### *Industrial Research*

Industrial research is conducted in Britain by private firms and by the industrial research associations. The larger firms, to an increasing extent, have their own laboratories, some of which are comparable in size and scope to the larger government research laboratories. But these laboratories exist mainly in the newer industries which were, in any case, born and bred on science and to whom scientific research is the life blood. In many cases such firms carry out not only applied research but also objective fundamental research relevant to their own interests. They are, of course, at liberty to keep the results of their scientific work to themselves, but in general they follow an enlightened policy and their staffs are important contributors to the world's scientific literature.

With a view to stimulating research by private firms the British Government has recently introduced certain fiscal changes. For many years now it has been possible for a "trader" to count current revenue expenditure on scientific research undertaken in relation to his trade as a deduction in computing profits for income tax purposes. But as from April 6, 1946, provision has been made whereby capital, as distinct from current, expenditure, is allowable for income tax purposes by five equal annual installments. For this purpose capital expenditure may relate, say, to the building of research laboratories or the installation of pilot plants.

### *Encouraging Research of Industrial Firms*

But in considering industrial research in Great Britain, we are at once faced with the fact that over 98% of our firms employ less than a hundred workers, so that although it is admitted that research always pays a dividend if you do enough of it, to a small firm without considerable financial reserves industrial research on its own account must often appear as a risky adventure and beyond its means. This difficulty has been met to a considerable extent by DSIR which is charged with the duty of encouraging research in industry.

The main method by which we have done this is by the formation of research associations each on a co-operative basis to serve the needs of particular industries. These research associations are self-governing bodies formed on a national basis, financed mainly by the contributions of their member firms but supported by substantial grants from the DSIR, the size of which is related to the amounts raised by the industries themselves.

There are now 35 or more of these research associations and their expenditure on research is nearing £1,500,000 per year, having risen from a little over £250,000 in 1934 to £500,000 just before the war. I should not be at all surprised myself to see this figure more than doubled in the next few years.

The industries covered by research associations include iron and steel, cast iron, nonferrous metals, welding, all the textile industries—linen, wool, cotton, silk, and now rayon—laundry, pottery, leather, boots and shoes, the electrical industries, paper, printing and packaging, automobiles, rubber, paint, food processing, confectionery, internal combustion engines, and shipbuilding. In the past six months it has hardly been possible to keep pace with the new research associations, so quickly are they being formed. Among these newer ones are machine tools, marine turbines, jute, baking, and felt.

For a very modest contribution, less than the cost of a single junior research worker, a small firm is enabled by joining a research association to share in research costing thousands of pounds, and in some

cases hundreds of thousands a year. The research associations also keep their members informed on scientific and technical developments throughout the world, provide them with advice on their day-to-day problems, and ensure that the industry as a whole has an opportunity of receiving early knowledge of developments likely to affect the future of their industry.

One thing which I am afraid tended to hinder the growth of cooperative research in the past was the rather touching belief of many firms that they possessed knowledge and trade secrets which were unknown to their competitors, and that this might be revealed if they collaborated in research. The manner in which firms had to work together in the war has done much to destroy this fear. An interesting side light on this matter are the remarks of the managing director of one of our leading aircraft firms. He said: "When the war began we thought that we knew a great deal more than our competitors, but when we were forced to share our knowledge with them we found they knew about just as much as we did and that the gaps in their knowledge and ours were about the same. What surprised us all still more was that when we had to share our knowledge with our American allies we again found that the gaps in their knowledge and ours were just about the same."

### *Conclusion*

Perhaps I may be permitted to devote the last section of my discourse to personal views rather than to factual matters. I strongly believe that the scientific life should be one of intellectual adventure. It seems to me that this can characterize it whatever its objective. We must recognize and encourage the enthusiasm of the chase as well as the attainment of the objective. I also want to break down the old false barrier between the so-called pure and applied divisions of science, for the whole field seems to me essentially one and its parts are interdependent. We are sometimes sufficiently aware of possible practical applications not too far distant for such recognition to influence our choice of subject. But we must beware of too much restriction of the scientific front. Man is not all-prescient; and nature has many surprises.

As to the scientist himself, I believe that he should serve, and not dictate to, mankind. But he has the important dual mission not only of uncovering nature, but also of interpreting it to his fellow men. Then, the consequences of scientific effort being understood by the community, any vital decisions on use must be taken together. Science is too serious a matter to be left to the scientists.

But here I am bound to confess that I see a certain danger, at any rate in my own country. I cannot but feel that there is a tendency in our educational system for scientific specialization to be introduced too soon. A scientific man should also be the complete "citizen of the world." He should not only be fit to live, but also fit to *live with*. This can only be brought about if his later specialized training is based, and continues to be based, on a broad cultural background. Only in this way can the scientist enjoy the necessary human fellowship with the rest of mankind. But with science destined to play such a vital part in molding the future of our civilization, it seems to me essential that, in a democratic community, the public, who ultimately should control the destiny of the nation, should make its own effort toward understanding. Too often, and regrettably, the average citizen is apt to associate science with magic and with something that gets into the headlines.

As a first step in this direction I feel that we should start with our educational system which, I think all would agree, should not be merely an implement of vocational training. It is not necessary to be a maker of science in order to understand its history, its content, and its significance. There is a recently published American book which has made a great impression on many minds in my country. It is entitled "A State University Surveys the Humanities" and consists of a series of essays by members of the staff of the University of North Carolina. Among the many thoughtful and thought-provoking contributions to this scholarly volume there is one entitled "The Biological Sciences: The Sciences in the Humanities" by Robert E. Coker, who is strongly of the opinion that the general cultural value of science is not sufficiently appreciated in universities. He deplores the cultural distinction which is drawn between the arts and the sciences and believes "it arose and has persisted in part from the overconfidence of some scientists who have proclaimed a self-sufficiency for science. It derives also from the narrowly restricted vision of those who would teach the sciences as if they were useful only to equip individuals for earning a livelihood or to enable mankind to have more gadgets and physical confort s."

In another passage in the same essay Dr. Coker enunciates his main thesis simply and boldly. "The sciences," he claims, "take high rank among the humanities." I believe he is right if the sciences are taught as they could be, and should be.